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Physiological distress predicts surgical risk and complications: analysis of heart rate variability in the pre and post-operative period

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On Saturday, I was a surgeon in South Africa, very little known. On Monday, I was world renowned.

Christiaan Barnard

A ideia para este estudo surgiu no serviço de urgência, acompanhando o Prof. Dr. Gil Faria, já que a vontade em realizar a tese de final de mestrado em cirurgia era uma certeza. O gosto por querer saber mais sobre cirurgia surgiu nas aulas com este professor fantástico, que proporciona aos alunos uma filosofia de “aprender ao fazer”, pela paixão pela sua profissão que nos contagia e pela capacidade de fazer qualquer aluno acreditar que há muito mais para descobrir e que qualquer um de nós o poderá fazer. Foi aqui que surgiu a ideia: Porque não tentar descobrir algo agora? E se fosse a minha tese? Estas foram só algumas das razões pelas quais decidi que o fim destes 6 anos de curso teriam que ser terminados em grande, em cirurgia.

Este estudo representa uma ideia, uma suposição, de que talvez fosse possível associar a agressão cirúrgica a uma medida de complexidade que pouco havia sido estudada, e nunca em cirurgia. Foi desde logo entusiasmante, havia a possibilidade de fazer a diferença.

Apesar de imediatamente apaixonante, a logística que envolveu o presente estudo foi difícil, tanto a nível técnico, como na disponibilidade dos doentes. No entanto a disponibilidade de médicos e enfermeiros do serviço de Cirurgia 1 foi crítica para que este trabalho ganhasse vida.

Por outro lado, e acontecendo paralelamente, é sabido que o ultimo ano do estudante de medicina não é fácil. Foi difícil conjugar o estudo que tanto caracteriza este ano, e ainda o estudo e o tempo para que esta investigação acontecesse, mas foi possível e não poderia estar mais contente.

Não conseguiria imaginar, nem quereria, que este percurso terminasse de outra forma. Este trabalho representa o fim e um início, com tudo aquilo que de melhor a medicina me pode proporcionar: Trabalho, paixão e vontade.

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Abbreviations list

BMI – Body mass índex

C-RP – C-reactive protein

Hgb - Haemoglobin

HR – Heart rate

HRV – Heart rate variability

ULF - Ultra low frequency

VFC – Variação da frequência cardíaca

VLF - Very low frequency

WBC – White blood cells

Abstract

Introduction

Heart rate variability (HRV) has been studied as a predictor of death and morbidity in trauma and sepsis. Surgery, as sepsis and trauma, is also an aggression to the organism. Our goal was to study heart rate variability after major abdominal surgery. Our hypothesis is that patients would suffer a decrease in HRV after major abdominal surgery.

Methods

We collected clinical and demographic data from 20 random patients. Continuous R-R intervals (in milliseconds) were recorded using a commercial Suunto Ambit R2 watch in the day before surgery and in the 1st and 3rd post-operative days, for 2 hours. HRV was calculated from the analysis of the continuous R-R monitoring and was processed to eliminate artefacts and cut to uniform the length of the signals. Patients with pace-makers or under B-blocker therapy were excluded from the study.

Results

The presence of comorbidities, such as, high blood pressure, type 2 diabetes mellitus, smoking habits, and globally the Charlson comorbidities score, were non-significantly related to lower levels of pre-operative HRV. This is reinforced by the association of higher POSSUM and APACHE II scores with lower levels of HRV.

The balance of the cardiovascular system was related to HRV: heart rate on day 1 was inversely correlated with HRV ($p=0.05$) and higher diastolic blood pressure related with increased HRV. ($p=0.04$).

Patients proposed to gastric surgery had lower HRV values (explained by the severity of the disease and general state of the patients)

HRV declined significantly in the 1st post-operative day, and recovered to baseline values on the 3rd day after surgery.

Conclusion

HRV measurement correlated with validated risk scores for surgical patients, identifying patients at higher risk of mortality, intra and post-operative complications. Our preliminary report confirms that major abdominal surgery results in an early decrease in HRV. Most patients recover to baseline values by the 3rd post-operative day.

This finding might lead to a novel field of research of the physiologic impact of surgery and to evaluate its relation with surgical risk and complications.

Key words

Surgery, major abdominal surgery, surgical stress, heart rate variability.

Resumo

Introdução

A variabilidade da frequência cardíaca (VFC) tem vindo a ser estudado como preditor de mortalidade e morbilidade no trauma e na sepsis. Assim como estas duas entidades, a cirurgia também constitui uma agressão ao organismo. O nosso principal objetivo foi estudar a VFC após cirurgia abdominal *major*. A nossa hipótese é que a VFC diminui após cirurgia abdominal *major.*

Métodos

Foi recolhida informação clinica e demográfica de 20 doentes. Utilizando um relógio comercial Suunto Ambit R2, foram adquiridos intervalos R-R consecutivos (em milissegundos) durante 2 horas, no dia antes da cirurgia (dia 0) e nos dias 1 e 3 de pós-operatório. A VFC foi calculada através da análise dos intervalos R-R após o processamento prévio do sinal, eliminando artefactos e uniformizando a duração dos sinais de todos os indivíduos. Doentes com *pace-maker* ou sob terapia beta bloqueadora foram excluídos do presente estudo.

Resultados

A presença de comorbilidades, nomeadamente hipertensão arterial, diabetes mellitus tipo 2, hábitos tabágicos e o score de comorbilidades de *Charlson*, associaram-se de forma não significativa a níveis basais mais baixos de VFC. Estes dados são suportados pela associação de valores mais altos dos scores POSSUM e APACHE II a valores mais baixos de VFC.

O equilíbrio do sistema cardiovascular associou-se à VFC: demonstrou-se uma relação inversa entre a VFC e a frequência cardíaca do dia 1 ($p=0.05$) e direta com a pressão arterial diastólica ($p=0.04$)

Os doentes propostos para cirurgia gástrica apresentaram valores mais baixos de VFC (o que se explica pela severidade da doença e pelo estado geral dos doentes).

A VFC diminuiu significativamente no 1º dia de pós-operatório com recuperação para valores basais no 3º dia após a cirurgia.

Conclusão

A medição da VFC correlacionou-se com scores de risco validados para doentes cirúrgicos, identificando aqueles com maior risco de mortalidade e de complicações intra e pós-operatórias. Este estudo preliminar confirma que a cirurgia abdominal *major* resulta em diminuição precoce da VFC, sendo que a maioria dos doentes recupera para valores basais ao 3º dia do pós-operatório.

Este estudo poderá contribuir para o desenvolvimento de um novo campo de investigação no impacto fisiológico da cirurgia e na avaliação da relação entre a VFC e o risco cirúrgico e as complicações pós-operatórias.

Background

About 234 million major surgeries are performed every year worldwide. [1] In Portugal, in the year 2010, approximately 2510 major and medium surgeries were performed daily. [2]

Surgical procedures lead to a variety of physiological changes characterized by alterations in hemodynamic, endocrine and immune function, during the operative and post-operative period.[3] [4]

The homeostasis during surgery is acquired by changes that are responsible for a rapid adaptation of circulatory mechanisms to restore blood pressure and volume, activation of clotting mechanisms to reduce blood loss, the conservation of water and electrolytes and maintenance of acid-base neutrality. Volume depletion is the most important single factor that influences the systemic response to surgical trauma: the kidney, by the stimulation of anti-diuretic hormone, retains water and electrolyte; and the cardiovascular system, by sympathetic stimulation, increases heart rate, myocardial contractility, and peripheral vasoconstriction.[5-7]

A functioning immune system is essential after surgery in order to prevent postoperative complications, mainly infection. There is a balance between pro-inflammatory and anti-inflammatory cytokines, and in the first 36 hours, usually, the former predominates.[4]
Hormone, metabolic, immunological and hemodynamic responses characterize all this inflammatory state. Increased catecholamine, cortisol and anti-diuretic hormone release are responsible for restoring or maintaining normal blood pressure values, by the same mechanisms used during surgery. A hyper-metabolic state with higher resistance to insulin occurs in the first 4-5 days after surgery, leading to hyperglycaemia, which is going to nurture the injured tissues.[8] Local vasodilation, increased heart rate, increased cardiac output and increased respiratory rate are the response to the higher oxygen demand by the injured tissues, often succeeding in correcting the volume depletion.[4, 6, 7, 9-14]

So the development of this inflammatory state is one of the most important physiological changes after surgery. This condition affects several organs and systems, mainly the cardiovascular.[10, 15]

According to the chaos theory, increasing complexity is a marker of healthier biological systems.[16] People are dynamic biological systems and thus, we can speculate that healthier people have increased complexity.

Heart rate variability has been considered a marker of systems' complexity and can be determined by analysing R-R intervals from a continuous electrocardiographic record (EKG). [16]

Some studies have revealed the association between HRV and patients' severity in trauma or sepsis: decreased heart rate variability is associated with increasing mortality.[16-19]

Also, decreased HRV has been recognized as a marker of frailty: people with decreased HRV have increased mortality.[20]

To the best of our knowledge, HRV variability has not been studied before in surgical patients. Our goal is to study the complexity of biological systems after major digestive surgery. Since surgery (as sepsis and trauma), is an aggression to the organism [21], we hypothesize that after major surgery patients will suffer a decrease in complexity and in HRV.

Materials and Methods

After approval from the Institutional Ethics Review Board, we recruited a random selection of 20 patients proposed to major abdominal surgery at Hospital de Santo Antonio - Centro Hospitalar do Porto. We included patients proposed to gastric or colo-rectal surgeries between November 2014 and April 2015.

We collected clinical and demographic data. Continuous R-R intervals (in milliseconds) were recorded using a commercial Suunto Ambit R2 watch in the day before surgery and in the 1st and 3rd post-operative days, for 2 hours. Patients with pace-makers or under B-blocker therapy were excluded from the study.

Heart-rate variability was calculated from the analysis of the continuous R-R monitoring. All signals were processed before the analysis. Artefacts were excluded and all signals were cut to the same length. This processing is used to eliminate outlier intervals and to allow for comparison between the signals of all the patients, since the complexity measures are related to the signal length.

The statistical analysis was performed with the SPSS statistics version 20.0. All variables were tested for normality distribution by visual analysis of the histograms and using P-P plots and the Kolmogorv-Smirnov test of normality. For the non-normal variables, non-parametric testing was selected. The longitudinal assessment of change in heart rate variability was performed with a 2-way mixed model analysis of variance (ANOVA) with a Greenhouse-Geissler correction. Significant values were considered for p values <0.05.

Results

Patients' characteristics are presented on Table I and Table II. Half of the patients were females, most (85%) had history of previous surgeries and the more prevalent comorbidities were high blood pressure (40%) and type 2 Diabetes mellitus (15%). Most surgeries (65%) were on the colon and 55% were laparoscopic.

Table I – Patients' characterization

	n	%
Female gender	**10**	**50**
Previous Surgeries	**17**	**85**
Smoking history	**9**	**45**
High Blood Pressure	**8**	**40**
Type 2 Diabetes Mellitus	**3**	**15**
Heart disease	**2**	**10**
Chronic obstructive pulmonary disease	**1**	**5**
Surgeries		
Colon surgery	**13**	**65**
Gastric surgery	**7**	**35**
Laparoscopic surgery	**11**	**55**

The median age was 65 years-old and median body mass index (BMI) was 25 kg/m^2. Heart rate, systolic blood pressure and diastolic blood pressure had medians of 73/min, 131mmHg and 61mmHg, respectively. Pre-operative clinical and biochemistry values are reported on.

Table II - Population characteristics (Pre-operative parameters)

	Median	Minimum	Maximum
Age	**65**	**19**	**88**
Weight	**66**	**43**	**104**
Height	**1.64**	**1.53**	**1.73**
Body Mass Index	**25**	**20**	**34**
Heart Rate	**73**	**55**	**103**
Systolic blood pressure	**131**	**99**	**165**
Diastolic blood pressure	**61**	**49**	**91**
WBC (x10$^{3)}$	**6,62**	**2.87**	**11.04**
Haemoglobin	**12.9**	**5.2**	**15.7**
C-reactive protein	**1.41**	**0.7**	**21.7**
Fasting blood glucose	**96**	**72**	**163**

Tests for normality (Table III and Figure I) revealed that weight, C-reactive protein and fasting blood glucose distributions were non-normal.

Table III - Tests of Normality

Tests of Normality	
Kolmogorov-Smirnov	
	p
Age	**0.200**
Weight	**0.026**
Height	**0.200**
Body Mass Index	**0.200**
Heart rate	**0.200**
Systolic blood pressure	**0.200**
Diastolic blood pressure	**0.200**
WBC	**0.200**
Haemoglobin	**0.200**
C-reactive protein	**0.000**
Fasting blood glucose	**0.002**

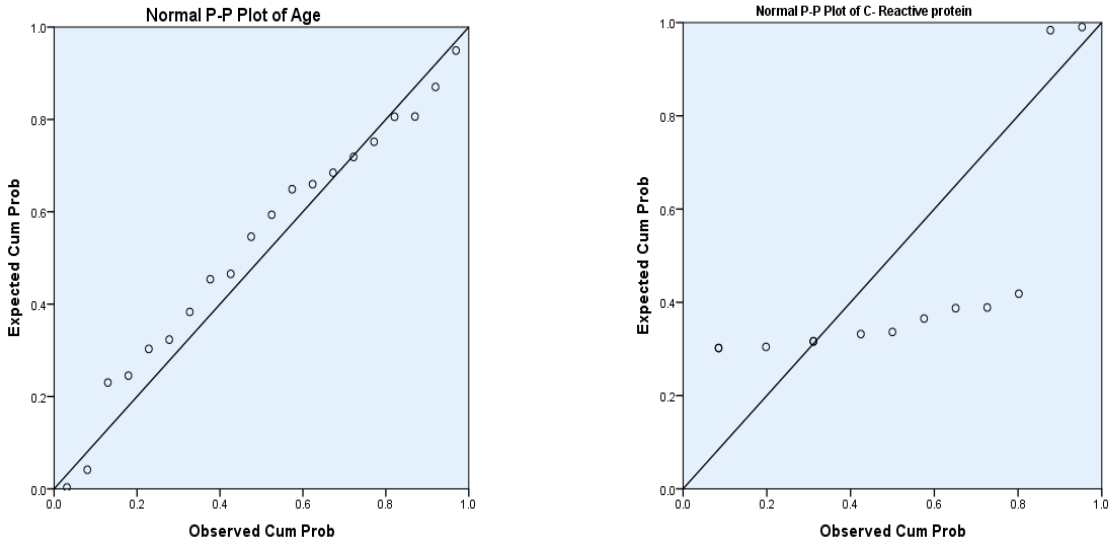

Figure I – P-P plots for age and C-reactive protein exemplifying a normal and a non-normal distribution.

Heart rate variability was measured in the pre-operative period, and on post-operative days 1 and 3. The variability measures are presented on Table IV. SDANN and pNN50 represent a time domain analysis and represent the dispersion of the signal around the median values of heart rate, analysed for a long period of time. Ultra low frequency (ULF) and Very low frequency (VLF) represent a frequency time analysis and represent the influence of the autonomous nervous system on the variation of frequencies. Alpha 1 is a non-linear method of analysing heart rate variability, measuring the complexity of the signal.

Table IV - Heart rate variability on days 0, 1 and 3 (median values)

	D0 SDANN	D0 pNN50	D0 ULF	D0 VLF	D0 Alpha1
D0	**50**	**0,036**	**41,4**	**64,3**	**1,04**
D1	**38**	**0,026**	**36**	**54**	**1,03**
D3	**49**	**0,01**	**37**	**65**	**1,07**

HRV variables were tested for normality – Table V. SDANN, ULF and VLF distributions were considered normal and pNN50 and Alpha1 were non-normal.

Table V - Tests of Normality (HRV)

Tests of Normality	
Kolmogorov-Smirnov	
	p
SDANN	**0.200**
pNN50	**0.000**
ULF	**0,105**
VLF	**0.182**
Alpha1	**0.003**

Because SDANN has a normal distribution, it's usable in all patients given equal lengths of the signal and is not affected by the respiratory rate, it was the variable chosen for comparing and analyzing HRV. Also, most reported studies have used SDANN due to its proven correlation with prognosis and because it represents a long-term measure of HRV, allowing a better understanding of its variation.

There were no significant relations between patients' characteristics and basal HRV (Table VI)

Table VI - Basal HRV according to patients' characteristics

	Yes	No	
	Day 0 SDANN (Mean ± STDev)		p
Female	**51 ± 26,4**	**52 ± 19.8**	**0.961**
Active smoking	**62 ± 23,5**	**51 ± 10.4**	**0.514**
High Blood Pressure	**45.5 ± 22.9**	**55.4 ± 22.5**	**0.368**
Type 2 Diabetes Mellitus	**33.3 ± 19.8**	**55.2 ± 21.9**	**0.127**
Age > 65	**53.74 ± 29.45**	**49.96 ± 15.46**	**0.727**
BMI >25	**48.54 ± 21.04**	**53.66 ± 10.49**	**0.630**
Co-morbidities	**51.22 ± 23.99**	**54.61 ± 15.73**	**0.819**
Surgeries			
Gastric surgery	**49.1±16.9**	**53.3±25.9**	**0.712**
APACHE >8%	**47.7 ± 17.38**	**57.7 ± 21.85**	**0.417**
POSSUM >0.8%	**49.94 ± 20.72**	**56.43 ± 25.78**	**0.402**
Charlson > 26%	**33.34 ± 19.79**	**55.20 ± 21.86**	**0.127**

Although not statistically significant, patients with higher comorbidities and risk scores, had lower HRV values.

Analysis of the SDANN (HRV measure) change between days 0 and 1 is presented in Figure II.

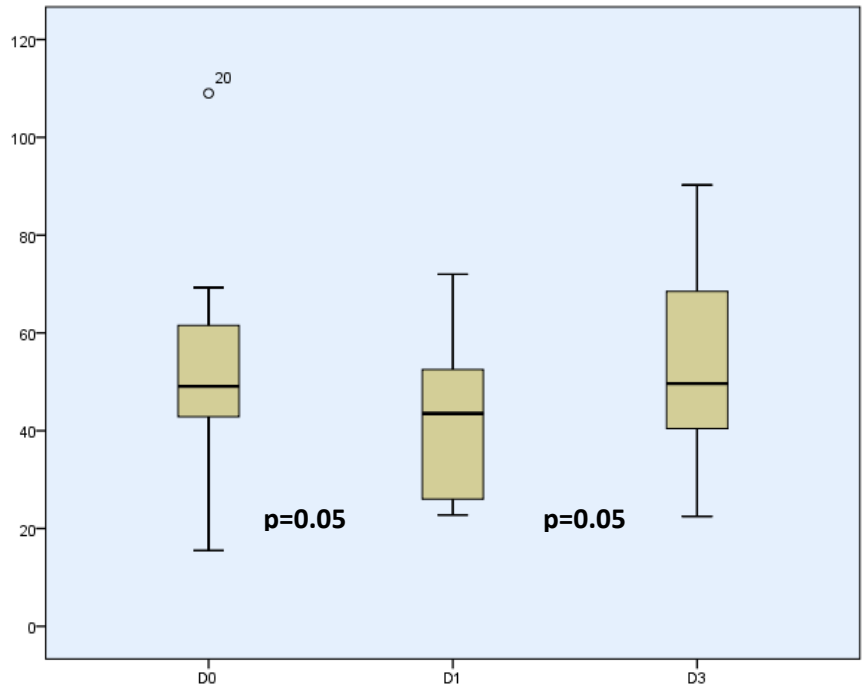

Figure II - Change in SDANN (two-way ANOVA with Greenhouse-Geissler correction)

Table VII - Change in HRV (Delta SDANN) according to patients' characteristics

	Yes	No	
	Delta SDANN (Mean ± STDev)		p
Female	**-12.36 ± 26.53**	**-10.21 ± 18.83**	**0.848**
Active smoking	**-36.33 ± 14.45**	**-7.87 ± 20.95**	**0.086**
High Blood Pressure	**-7.72 ± 13.03**	**-12.68 ± 25.26**	**0.686**
Type 2 Diabetes Mellitus	**-5.46 ± 18.06**	**-12.46 ± 23.22**	**0.634**
Age > 65	**-8.79 ± 29,69**	**-12.93 ± 16.41**	**0.716**
BMI >25	**-8.85 ± 12.09**	**-9.21 ± 29.29**	**0.979**
Co-morbidities	**-7.39 ± 21.64**	**-29.07 ± 16.41**	**0.126**
Surgeries			
Gastric surgery	**-8.00 ± 21.24**	**-13.48 ± 23.46**	**0.630**
Laparoscopic surgery	**-15.72 ± 20.54**	**-7.22 ± 23.78**	**0.446**
APACHE >8%	**-6.31 ± 29.15**	**-17.33 ± 18.83**	**0.399**
POSSUM > 0.8%	**-5.27 ± 26.34**	**-16.66 ± 19.55**	**0.337**
Charlson > 26%	**-5.46 ± 18.06**	**-12.46 ± 23.22**	**0.634**

The change in HRV, although not statistically significant was greater in female patients, active smokers and in laparoscopic surgery. Patients with higher risk scores, had lower change in SDANN on day 1. - Table VII

Table VIII - Correlation between SDANN and HR

		D0 SDANN	D1SDANN	D3SDANN
HR day 0	Correlation	**-0.197**	-0.186	0.355
	p	**0.419**	0.459	0.257
HR day 1	Correlation	-0.190	**-0.472**	-0.629
	p	0.451	**0.05**	0.03
HR day 3	Correlation	-0.095	-0.241	**-0.240**
	p	0.709	0.352	**0.477**

There is an inverse relation between HR in day 1 and SDANN (p=0.05). - Table VIII

Table IX - Differences between patients with gastric or colonic surgery

	Gastric	Colonic	
	Mean (SD) / n(%)		p
Female	**4 (57%)**	**3 (46%)**	**0.660**
Active smoking	**1 (14%)**	**1 (8%)**	**0.660**
High Blood Pressure	**1 (14%)**	**7 (52%)**	**0.069**
Type 2 Diabetes Mellitus	**1 (14%)**	**2 (15%)**	**0.951**
Age	**65.77 ± 12.83**	**60.53 ± 17.25**	**0.492**
BMI	**24.25 ± 0.50**	**26.69 ± 4.39**	**0.370**
Co-morbidities	**6 (86%)**	**11 (85%)**	**0.951**
Hgb	**10.97 ± 2.89**	**13.63 ± 1.97**	**0.030**
C-RP	**5.04 ± 8.50**	**4.18 ± 7.14**	**0.847**
Malignancy	**7 (100%)**	**9 (69%)**	**0.040**
Laparoscopic surgery	**1 (14%)**	**10 (77%)**	**0.005**
APACHE >8%	**2 (33%)**	**2 (17%)**	**0.453**
POSSUM >0.8%	**5 (83%)**	**4 (31%)**	**0.033**
Charlson > 26%	**1 (14%)**	**3 (23%)**	**0.660**

Patients with gastric disease had more often malignant disease, had lower levels of haemoglobin, more laparotomic procedures and higher POSSUM score.

Table X – Correlations between D0 HRV (SDANN) and BMI, Age and Blood pressure

		D0 SDANN
Systolic blood pressure	Correlation	0.215
	p	0.19
Diastolic blood pressure	Correlation	**0.393**
	p	**0.04**
BMI	Correlation	-0.007
	p	0.491
Age	Correlation	0.042
	p	0.432

Higher diastolic blood pressure in the pre-operative period was correlated with higher levels of HRV.

Discussion

Heart rate variability is a widely used non-invasive method to determine autonomic activity and its influence on cardiovascular system. HRV represents the imbalance on the autonomic system, decreasing with higher activation of the sympathetic over the parasympathetic system. It is known that it is decreased after cardiac surgery, representing abnormal and insufficient adaptability of the autonomic nervous system. Also, it has been shown to be a predictor of hemodynamic instability and mortality.[22, 23]

HRV has also been used to determine deterioration in clinically ill patients. The loss of heart rate variability has been associated with severity and risk of death in sepsis and trauma patients. [16-19] Surgery, as well as these two clinical situations, is an aggression to the organism, inducing an inflammatory response in the post-operative period, with a cardiovascular response characterized by increased heart rate and cardiac output. [4, 6, 9, 10, 12, 15]

Biological systems are complex both in structure and in function. In health there is diversity and variety but in disease that range is narrowed such that, according to the chaos theory, healthier systems are the more complex[16]. Measuring complexity is not usually easy and straightforward. There are several methods to measure it: changes on temperature and mobility of the breast were proposed to be associated with breast cancer; respiratory rate variability is higher in younger – healthier – people; and it was proposed that genetic mutations were associated with less complexity in the DNA structure.[24, 25]. In the present study, given its accuracy, ease-of-use, stability on time and reproducibility HRV was used as a marker of systems' complexity.[23]

For the best of our knowledge this is the first study about HRV after major abdominal surgery. Despite the small group of patients evaluated, we can assume that it is representative of the Portuguese adult population. Data from the Portuguese Society of hypertension in 2013 revealed that 42,2% of the Portuguese had high blood pressure (40% in the present study). On the other hand, according to the National Diabetes Observatory in 2012, 12,7% of all Portuguese adults aged 20-79 were diabetic (15% in the present study).

Since HRV is variable among different people, we measured individual HRV in the pre-operative period establishing the basal value for each patient. [26]

Several studies report that older patients have lower levels of HRV. Gender has not been proved to have a significant independent influence and the studies are controversial.[27, 28] Patients with chronic illnesses (such as diabetic neuropathy, congestive heart failure, high blood pressure, sleeping disorders, angina pectoris, or obesity) have lower levels of basal HRV.[20, 23, 29-34] Nutritional habits, such as a high fatty acids diet, tobacco and alcohol habits also have decreased HRV basal levels.[20, 35] Although differences were not statistically significant, our results are concordant with these findings.

On the other hand, it is known that HRV is inversely correlated with heart rate – the sympathetic activation which increases heart rate is associated with reduced HRV – though, pharmacological therapies with negative chronotropism, such as Beta-Blockers, are associated with higher levels of HRV.[30] In this study, patients under beta-blockers treatment were excluded. Even if patients' basal HR and HRV were not correlated in the present study, the fact that HR in day 1 and HRV were correlated, might indicate that under control of the sympathetic autonomous system, both HR and HRV suffer a change after abdominal surgery.

In fact, HRV seemed to be a good measure of the more subjective "frailty". It has a probable correlation with the presence of co-morbidities, which underlines that HRV measurement and the systems' complexity are in fact, associated with more severe disease and less entropy. Despite the lack of significance, HRV measure was consistently lower in patients with smoking habits, high blood pressure and type 2 diabetes mellitus when compared with patients without those comorbidities. Furthermore, the unspecified presence of co-morbidities, was also related to lower baseline HRV. To underline this findings, patients with higher risk in pre-operative scores, such as Charlson comorbidities and POSSUM, have decreased HRV.

We also found differences between HRV according to the organ affected. Patients with gastric disease had lower levels of SDANN in the pre-operative period when compared to colon disease. Despite the lack of statistical relevance, this tendency could be explained by the differences between the illnesses and its diagnosis. Gastric cancer is usually found at an advanced stage, when the patients have lost weight and present constitutional symptoms, while colorectal cancer patients are usually diagnosed by screening colonoscopies.[36, 37] Overall, patients with gastric surgery seem to be more frail and with a more advanced disease burden. In fact, when comparing both gastric and colonic patients, we found that patients with gastric disease had lower levels of haemoglobin

(p=0.03), were more often malignant (p=0.04), had higher POSSUM score (p=0.03) and the preferred surgical approach was laparotomy (p=0.005).

There was no significant correlation between SDANN in the pre-operative period and pre-operative measurements, such as vital signs or age. Higher levels of diastolic blood pressure are associated with higher levels of HRV (p=0.04). In fact, diastolic blood pressure is mainly affected by the autonomous nervous system. Higher parasympathetic activation is related to higher levels of diastolic blood pressure and with higher levels of HRV.[38] The lack of significant associations between HRV and some of the patients' characteristics might be due to the small size of the sample and to its heterogeneity. Only a greater sample will allow for a more robust and multivariable analysis of the relations between HRV and patient characteristics.

Since major surgery is an aggression to the organism and it disrupts the normal physiologic functions, it was expected that HRV would decrease after major surgery. The most important result of this study is that, in fact, there is a significant decrease in complexity (HRV) in the first post-operative day. The recovery of the "normal physiology" happened by the 3rd post-operative day, with patients resuming their baseline HRV.

HRV recovery after cardiac surgery has been widely variable: some patients recover in a few days and others can still be recovering to basal HRV one year after surgery.[23, 39] In our study, patients recovered to their basal levels by post-operative day 3. We did not identify which factors would predict HRV recovery (or magnitude of decrease after surgery), but this might be a novel path of research in surgical physiology.

Although the number of patients studied and the number of complications occurred after surgery did not allow us to study the impact of HRV on surgical complications, patients with higher pre-operative risk assessment (using the POSSUM score), higher risk of in-hospital mortality (using APACHE II) and higher risk of 1-year death (Charlson comorbidities score) had lower baseline levels of HRV. Although this difference did not reach statistical significance, these associations are plausible and warrant further research.

Conclusion

As hypothesized HRV is a good measure of frailty, being non-significantly associated with comorbidities, such as type 2 diabetes mellitus, high blood pressure and smoking habits. Also, risk scores such as POSSUM, APACHE II and Charlson comorbidities score had a non-significant association with HRV.

HRV was associated with variations on cardiovascular measures, such as heart rate and blood pressure. There is an inverse relation with heart rate, which represents the disproportional activation of the sympathetic nervous system. On the other hand there is a direct relation with diastolic blood pressure, which is mainly affected by the parasympathetic nervous systems, proving its protective function on the cardiovascular system.

Patients with gastric disease had significant lower levels of haemoglobin, more malignant disease, higher APACHE II score and higher need for laparotomic surgery, confirming the frailty of these patients. Non-significant lower levels of HRV were found in patients proposed to gastric surgery.

The main conclusion is that HRV decreases on day 1 after major abdominal surgery, recovering to baseline on day 3. This finding might lead to a novel field of research of the physiologic impact of surgery and to evaluate its relation with surgical risk and complications.

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